LIGO

LIGO Data & Computing Update

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LIGO Laboratory at Caltech

12th Meeting of the LIGO Laboratory PAC
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Cambridge, MA

Outline for this talk

- Simulation & Modeling
- Data Analysis Systems
- Grid Computing
- Staffing

LIGO Modeling & Simulation Activities Overview

- e2e development began after LIGO I design was essentially complete
  - » e2e used by M. Evans in successful redesign of LIGO I lock acquisition control system
- Major ongoing effort at present:
  - » Model refinement, speed-up of code
  - » Representation of realistic noise performance of the locked state interferometer
- For the future:
  - » Integration of CDS real time code for *as-built* LIGO length and alignment control system into the simulated interferometer model
    - – Discussion has just begun …
    - – But not likely to happen due to limited time, manpower resources

First generation LIGO simulation: *Han2k*

- Purpose
  - » Design and develop the LHO 2 km interferometer locking servo
  - » Simulate major characteristics of length degree of freedom below 20 Hz.
- Simulation includes
  - » Scalar field approximation
    - – 1 DOF, TEM_{00} throughout model
  - » Saturation of actuator drivers
  - » Simplified seismic motion with low-f correlations
  - » Analog length control, with *no* angular control (i.e., 1 DOF)
  - » *No* additional noise sources
    - – no frequency noise, shot noise, sensor/actuator/electronic noise

LIGO Second generation LIGO simulation: *SimLIGO*

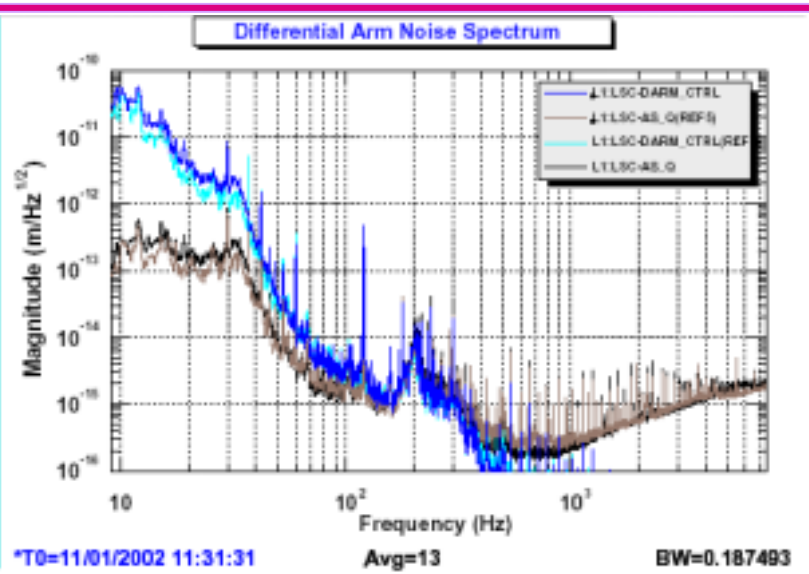
- Purpose
  - » Quantitative noise and performance estimation of as-built interferometer
  - » Assist noise identification and reduction, lock stability studies during commissioning
- Simulation includes
  - » As-built optical and mechanical parameters
  - » Seismic motion correlations among chambers
  - » 3D mirror with 4 sensors and actuators
  - » Digital length control system
  - » Alignment control via wavefront sensors and/or optical lever
  - » Digital suspension controller
  - » Common mode servo
  - » Mode cleaner with suspended, controlled small optics

Noise sources in SimLIGO

- Interferometeric
  - » Optical asymmetries
    - – reflectivities, transmissivity, length, radii of curvature, phase maps, …
    - – Non-normal incidence -- wedge angles, Earth curvature
  - » Scattered light
- Mechanical
  - » Wire resonances, test mass internal modes
- Sensing, actuation, digital real-time electronics
  - » Photo-detector, coil drivers
  - » Whitening/de-whitening filters, anti-aliasing
  - » ADC, DAC, digital transfer functions

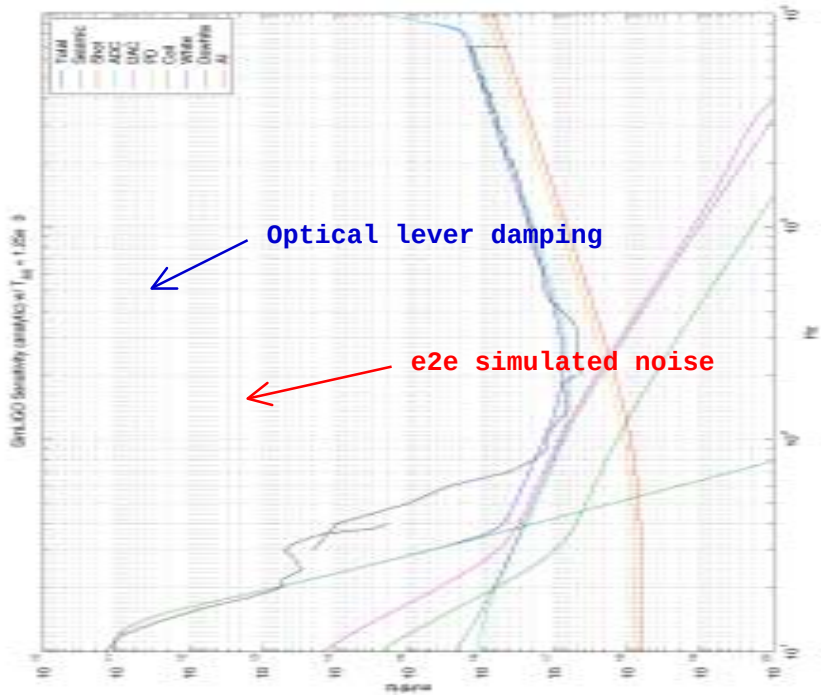
Simulation of sensitivity curve

noise by realistic simulation



Simulation includes:

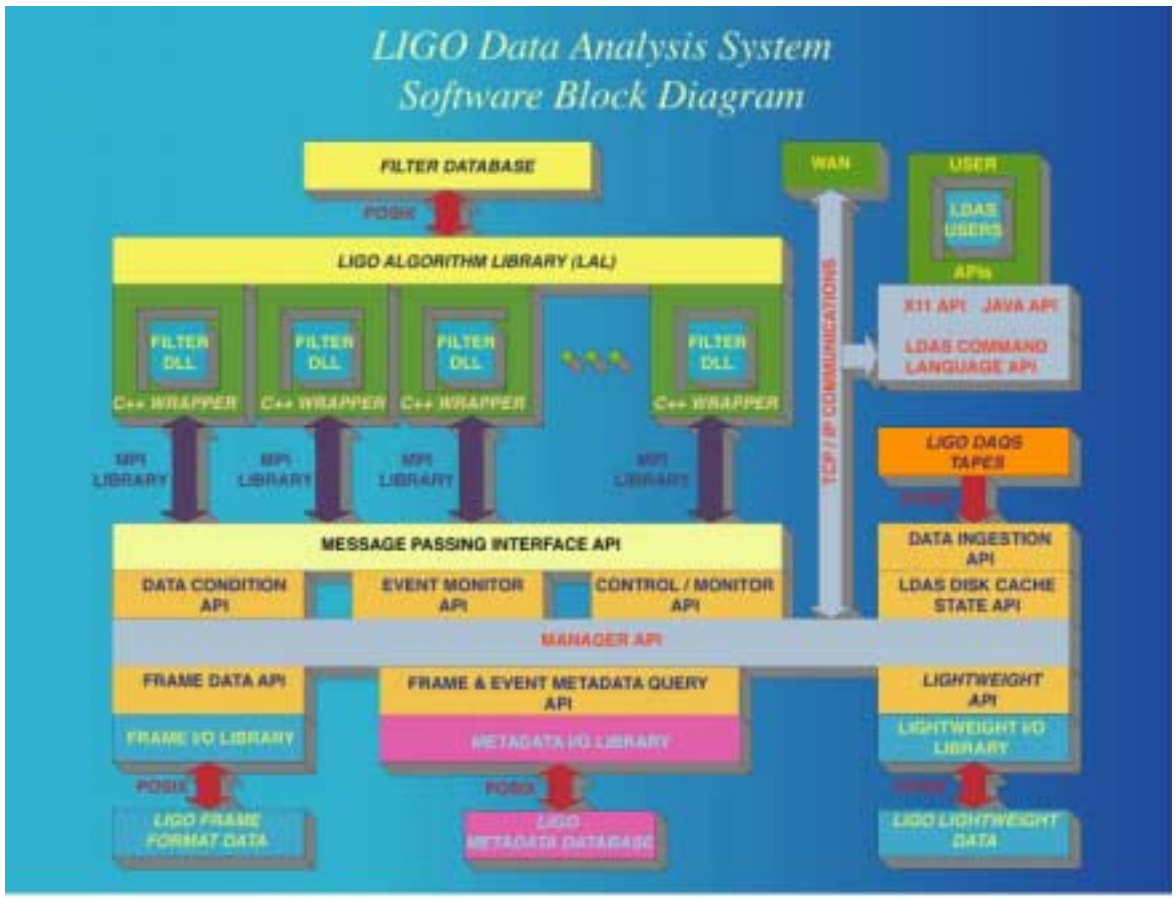
- Locked interferometer
- Mechanics
- Sensor-actuator, optical lever damping
- Servo electronics
- Signal extraction
- Simulated and measured noises



e2e -- future plans

- Evaluation of the as-built LIGO performance
  - » Identify minimum achievable noise performance for the as-built design
  - » Study, quantify specific noise sources and issues:
    - – bi-linear couplings, non-linearities, non stationarity, transients, lock instabilities, etc
  - » LIGO simulation package is ***ready***
    - ✓ Length control: complete
    - – Alignment control: available soon
- Ultimate success determined by adoption & use …
  - » Hardware experts know the important problems
    - – Lock acquisition was successful because it was a collaboration between simulation and interferometry experts
    - – Simulation group is small and needs to leverage off other within laboratory, LSC
  - » Documentation is almost complete
    - – How-to pages: setting up new models, running, …
    - – Tutorial, SimLIGO manual, physics models embedded in e2e simulation, …

Data Analysis
- Software -



LDAS Software is nearly complete!

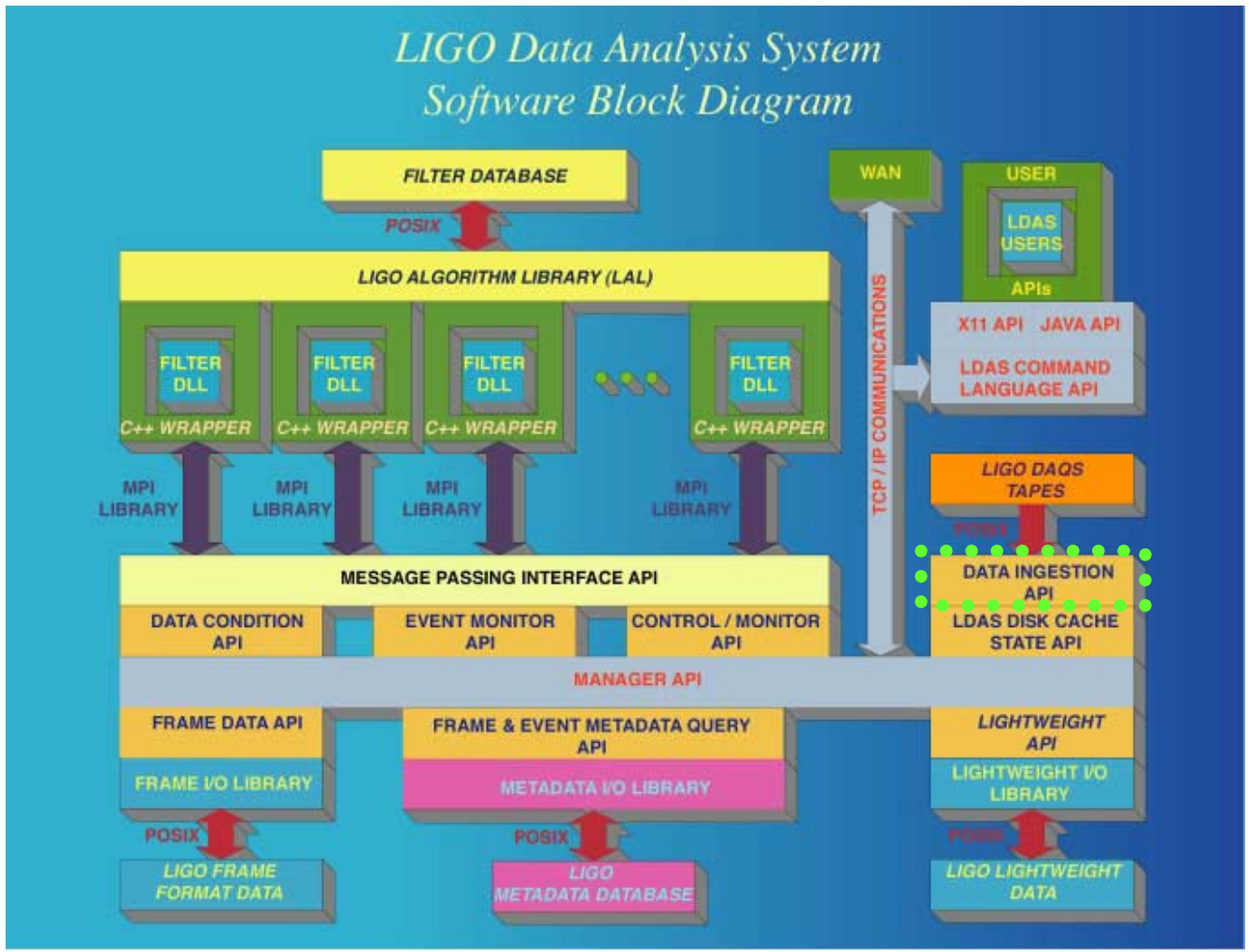
S1 release of LDAS: LDAS-0.3.0 (beta)

LDAS-0.3.0

- **Only one module left to build**

dataIngestionAPI:

- Basic functions needed with the beginning of the Engineering Runs.
- Scripts external to LDAS developed to carry out these functions.
- Script to recording data to tapes at sites can be controlled and monitored using LDAS's controlMonitorAPI.



E7
LDAS Job Summary

28 December 2001 - 14 January 2002

	Hanford LDAS	Livingston LDAS	MIT LDAS	CIT-TEST LDAS	TOTAL
Total Jobs	63600	48775	280	915	113570
Database Rows	4188188	2789132	1062	2096	6980478

- **LDAS version 0.0.23 (alpha code) ran for full E7 Run:**
  - **28 December 2001 - 14 January 2002**
  - **Approximately 1 job every 10 seconds (averaged).**
  - **Approximately 50 DB rows every 10 seconds (averaged).**
- **> 90% of jobs completed successfully**
  - **LHO: ~ 92%; LLO: ~95%; Not checked elsewhere.**
- **However … pre-release testing predicted ~0.3% failure rate …**
  - **Dominated by dataConditionAPI thread problems.**
  - **A fraction also due to mpiAPI/wrapperAPI communications issues.**
  - **Rare intermittent isues (difficult to debug) also suspected.**

E8
Reduced Data Set (RDS) Production
7 - 9 June 2002

- Ran with LDAS version 0.2.0 (first beta release) during E8
- University of Oregon (Isabel Leonor) led effort to write RDS frames
  - » Approximately 120 channels out of the 5000 selected out.
  - » Approximately 20 fast channels re-sampled by factor of two.
  - » Each RDS frame 20% smaller than corresponding raw frame.
- LDAS 0.2.0 unable to keep up with data rate as it wrote RDS frames!
- Repeated Test 2 weeks later at Hanford using pre-release version 0.2.55 of LDAS
  - » Increased number of channels to 152 (per S1 Run Plan)
  - » LDAS able to process 80 seconds data in 35 seconds when IFO in lock ... however … Discovered that ***out of lock*** processing time grew from 35 seconds to 155 seconds
    - – Isolated to sample values below 10^{-24} in the DARM control channel tickling a peculiarity in floating point performance on Suns using GCC compiler.
    - – Value of 10^{-24} in DARM written by realtime control system to replace “0” in order to avoid 1/0 in matrix inversion.

LDAS at MIT

- LDAS at MIT has become central to analysis activities within the BURST Upper Limits Group.
  - » See http://www.ligo.caltech.edu/LIGO_web/0203news/0203mit.html
- *LDAS used by Sylvestre at MIT to analyze E7 data and contributed to his recent Ph. D. dissertation*.
- Burst Group worked with LDAS development team to test pre-Science Run version of LDAS.
- As part of the analysis of E7 data, 6.5 days of E7 data were analyzed in a single day:
  - » 1554 jobs submitted to LDAS-MIT and completed successfully
  - » (3 DSOs) x (2 IFOs) x (1 waveform) x (7 amplitudes) x (37 360 sec intervals)

Individual LDAS Account over Secure Website

- **Individual accounts provided to individual users**
  - **No more shared user accounts!**
  - **Addresses long standing issue raised in NSF review.**

LIGO

- Control and Monitor API

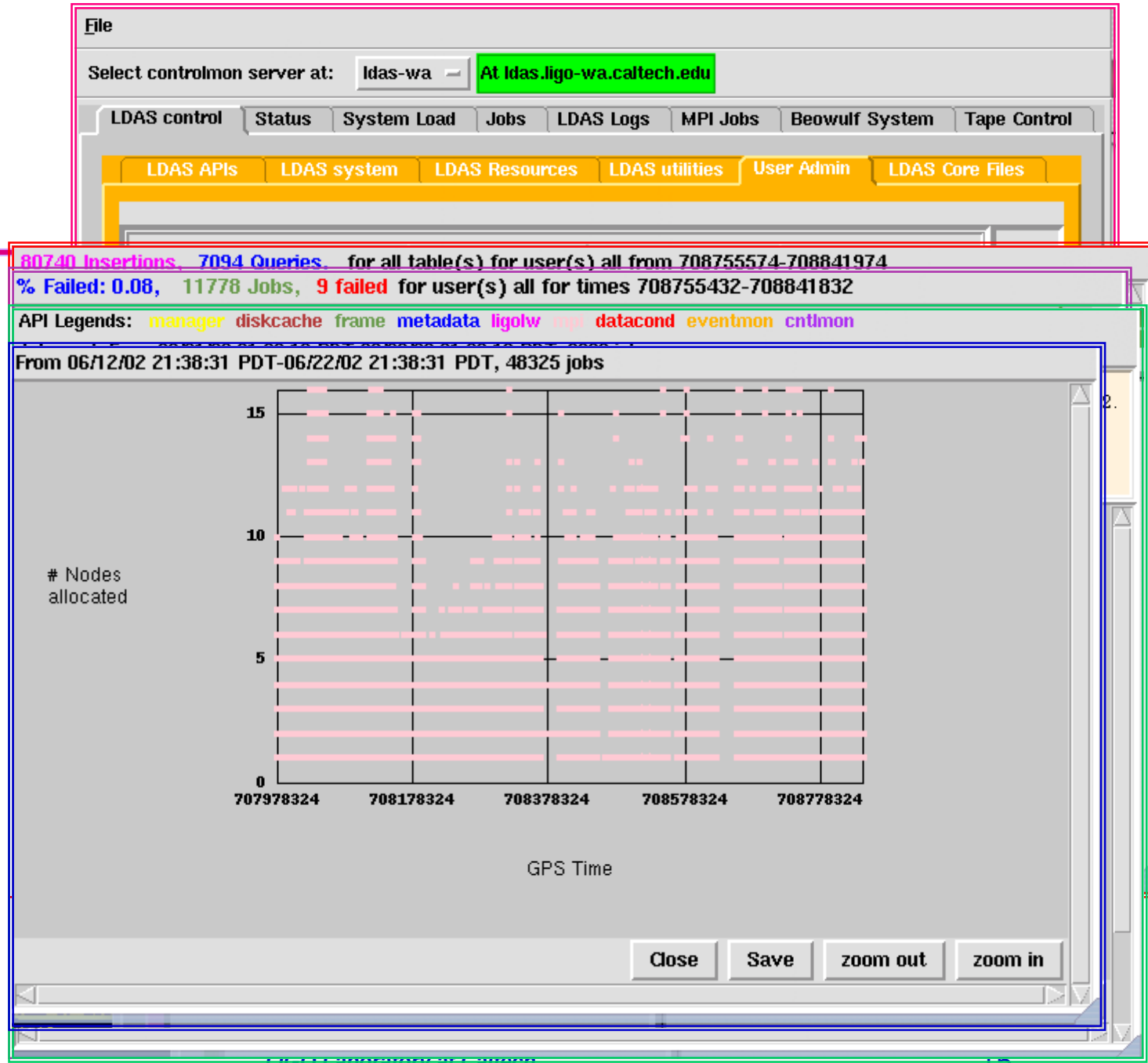
- user accounts management

- DB2 usage statistics

- user job statistics

- API memory usage

- MPI node usage statistics



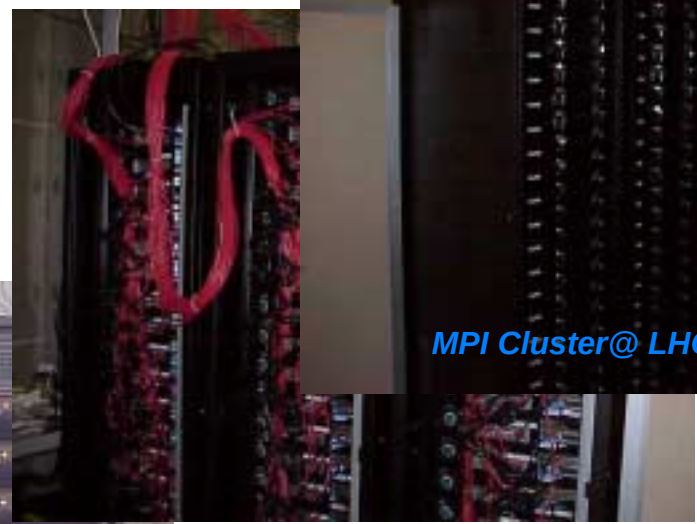
LDAS Plan for S1 Run

- Third beta release of LDAS will be used (version 0.3.0)
- Exhaustive testing of release for three weeks prior to S1:
  - » First week consisted of internal testing and bug fixing
  - » Second week continued internal testing and began integration testing with LAL and LALwrapper codes
  - » Carried out collaborative RDS testing at LHO and Burst Group analysis testing at MIT in the third week.
  - » Pushed pre-release 0.2.58 to UWM one week before S1 Run.
- Push release to all Laboratory sites (just) before S1 begins.
  - » “Just in time delivery”
- LSC (through LSUG group) will work with LDAS to “ramp” up to the S1 Run analysis plan.

Issues from LDAS software

- Version 5 Frame Specification significantly delayed and has resulted in some loss of schedule and reduced functionality for the Science Run.
- Reduced Data Sets are not very reduced!
  - » Frame size (>20% of raw data) taxing the current capabilities of LDAS and will demand reworking some of the frameAPI to be able to support this load.
- It is demanding to develop beta level code while supporting use of LDAS for science *and* supporting growing population of LSC users, LDAS installations.
- LSC participation in code (algorithm) development has significantly decreased due to change of focus towards Upper Limits Group activities.
  - » Needed signal processing functionality not yet unimplemented: Kalman filter, SI units management, process history, filter coefficient tracking, test signal generation, data type conversion (real->int), data alignment - handling filter delays
- LDAS use model evolution continues
  - » continued need for programming activities vis-à-vis science

Data Analysis
- Hardware -



LDAS S1, S2 Configuration

"Increase computational capacity over E7 and investigate advanced storage configurations but delay full compute farm deployment until S3."

	SAN (TB)	IDE (TB)	CPU (Aggregate GHz)	Tape (TB)
LHO	10		139	2
LLO	5		107	2
CIT	3		34	90
MIT	1	2	45	0
DEV	1		25	2
TEST	1		8	0

SAM-QFS vs HPSS

Last major trade study, to be completed by S2:

- SAM-QFS - Sun Microsystems acquisition (LSC), provides alternative to HPSS for integrated mass storage (disk+tape)
  - » http://www.sun.com/products-n-solutions/hardware/docs/Software/Storage_Software/LSC/index.html
- SAM-QFS advantages
  - » Simplicity/reliability
  - » Media import/export
  - » License cost allows for use at observatories
  - » Disaster recovery (GNU TAR)
  - » Metadata performance (x1000)
  - » Single vendor solution (server, software and OEM storage)
  - » Reduced dependency on CACR
- HPSS advantages
  - » Integrated several man-years experience
    - – …which is why we are looking at SAM-QFS …
  - » Free at Caltech
    - – cannot be used other Laboratory sites
  - » **35TB** successfully stored to date

Future hardware for S3:

- Additional Fibre Channel ports to connect remaining 2TB of disk at LHO and 1TB at LLO.
  - Enables direct access to the raw frames from additional servers, e.g., CDS and GC.
- Tape drives for archive system at Caltech.
  - The present prototyping set of 2 STK9940A drives will be enhanced with ~8 STK9940B drives in time for S2.
- Tape robotics at LHO and LLO.
  - If SAM-QFS is chosen over HPSS the same tape drive technology will be installed at the Observatories as at the central archive at Caltech.
  - Allows the direct ingestion of tapes without having the need for media-to-media copying.
- Large volume RAID storage @ Caltech, in front of tape archive.
  - Use inexpensive disk storage ($4k/TB) to build up ~50 - 100 TB of spinning storage in front of tape archive
  - Consider this “consummable” -- build up as needed as data volume grows.
- S3 Beowulf clusters :
  - The initial LDAS science run hardware configuration will be purchased in 4Q02-1Q03 and comprise ~400 compute nodes.
  - The interesting choice between ~3GHz P4 and 64-bit AMD/Intel platforms (if available).

Future hardware for S3:

- S3 Server configuration:
  - Data conditioning servers will be upgraded to Science Run configuration.
    - The desire to get to 64-bit platforms may push this out until 2-3Q03 (and hence expend monies from Operations rather than Construction -- *treat as an upgrade*).
  - Accrued experience with Sun V880 SPARC servers shows full more powerful configurations needed
    - Currently 50% populated with 4 processors
    - Additional 900-1000MHz CPUs will be added to those servers that have a demonstrated need, i.e., database, gateway, and/or dataserver.

- Inter-LDAS communications:
  - Need to facilitate the direct communication between database instances at different LDAS sites
    - Support efficient DB federation and replication
    - Laboratory-wide LDAS Virtual Private Network (VPN) will be installed.
      - Initial tests have been with OpenBSD on Intel hardware but this may change.

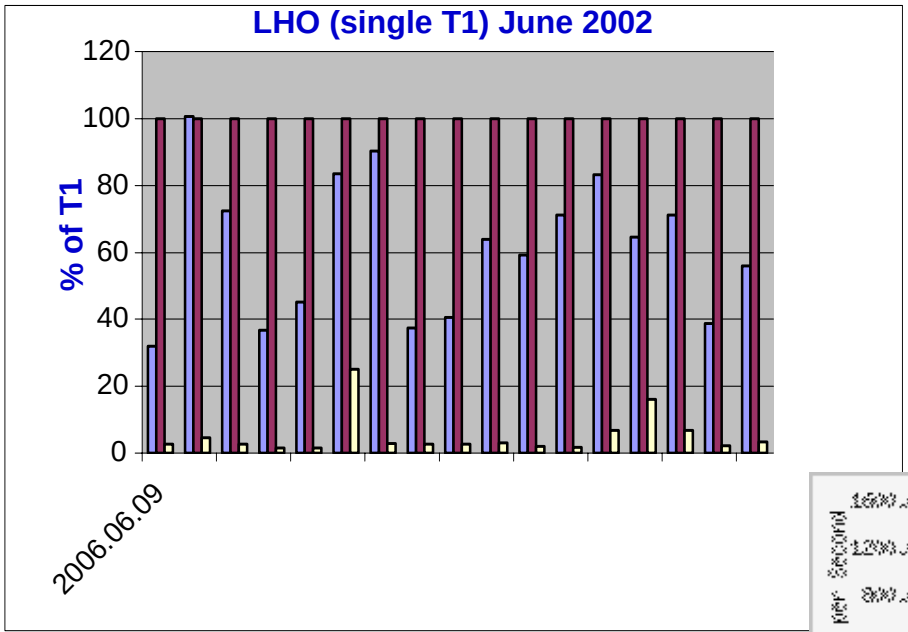
LIGO

Data Analysis
- Wide Area Network (WAN) -

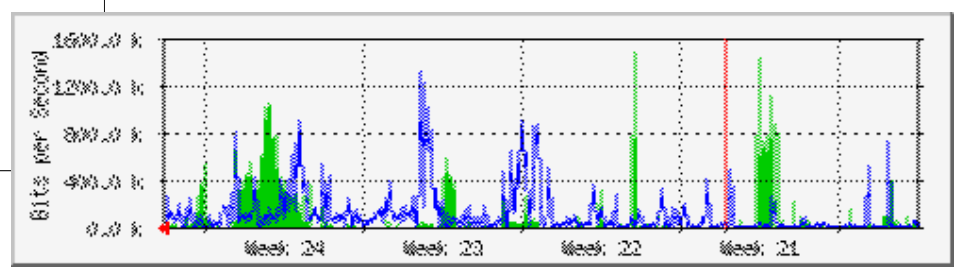
LIGO WAN

- Both LLO, LHO site connections are becoming saturated:
  - » T1 at LHO provided under MOU with DOE/ESnet
  - » 2xT1 at LLO provided through State of Louisiana Dept. of Telecommunications, via LSU.
- Increased traffic:
  - » Collaboration access to on site data
  - » Video for remote control rooms at Caltech, MIT
  - » LDAS data transmission, SW synchronization
- FY 2002 - 2006 Operations proposal contained budget for WAN upgrade to OC3
  - » Recommended also by previous NSF review panels
- Budget item *(for entire FY2002 - 2006 period)* eliminated to meet reduced funding profile guidance from NSF
- Presently exploring options for bandwidth upgrades that can fit into current budgetary constraints
  - » Identify non-recurring & recurring costs, develop a Change Control Board request and formulate a compelling argument for re-allocating funds for WAN upgrade

Statistics for WAN



LLO (dual T1), June 2002.



- LHO frequently saturates
- LLO is at 50% of 2xT1 during peak periods

LIGO WAN

- LHO
  - » Landscape of options has changed markedly over past 18 months
  - » New PUC enterprise, Energy Northwest (ENW), has installed fibre-optic infrastructure along the power grid rights-of-way throughout Washington
  - » Provides good service at reasonable cost for government, non-profit organizations - Battelle/DOE have already migrated to ENW
  - » *Cost of OC3 is expected to be ~13X less per Mbps than present T1 costs:*
    - – *OC3 annual costs would be additional $84k/year over what LIGO pays for T1*
  - » LIGO will continue its MOU with DOE/ESnet and share infrastructure, BW with PNNL/Battelle
    - – Mutual cooperation between NSF, DOE deemed important to PNNL, LIGO
  - » Awaiting quote for service from PNNL, ENW in order to formulate a proposal to LIGO Laboratory Directorate

LIGO WAN

- LLO
  - » Unlike LHO, the LA State infrastructure is linked to commercial enterprise
    - – Market rate for bandwidth in southeastern US is higher
    - – Fewer options (only Bell South)
      - Several expected competitors aborted plans after the *.com* collapse in FY2000-2001
  - » Presently in a “wait and see” mode, while identifying options
  - » Two factors mitigate situation vis-à-vis LHO:
    - – Data rate, volume is 0.5 as great
    - – Present bandwidth is already twice as great
      - 2 T1 lines in place vs. 1 at LHO

LIGO

Data Analysis
- Grid Computing -

GriPhyN: Grid Physics Network

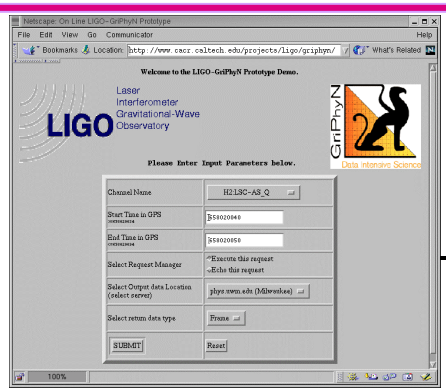
iVDGL: International Virtual Data Grid Laboratory

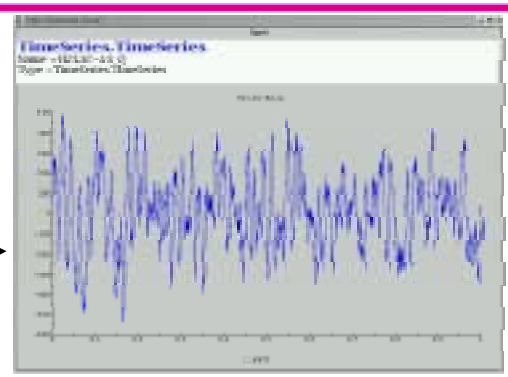
Grid activities
GriPhyN & iVDGL

- LIGO/Caltech, UWM, PSU members of collaborations
- GriPhyN - CS + Applications research focused on:
  - » Virtual data in LIGO analysis
    - – Use of transformation catalogs to keep track of previously requested, performed transformations that can be used to accelerate data requests
    - – Determine if the data product is instantiated, if so where, if not, how to compute it.
    - – Plan & execute data movements and computations required to support specific analyses
  - » LIGO data mirroring using gridtools
    - – Automated, robust replication between Tier 1 & Tier 2 sites
  - » Developing an interface between the grid environment and the native LDAS environment
    - – Extending LDAS into a grid-enabled environment -- longer term goal
  - » Grid security infrastructure
    - – Provide data access only to collaboration members
    - – Provide a level of security to LDAS computing

GriPhyN Prototype

SC01 Virtual Data Replication Demonstration





Desired Result

Single channel time series

LIGO-G020266-00-E

LIGO

Virtual Data Prototype Functionality

- The detailed prototype functionality was as follows:
  - » User inputs request using a web browser. User can specify:
    - – Data channel name
    - – Time of interest
    - – Desired output data location
  - » Request is transformed into XML
  - » Request Interpreter: Understand an XML-specified request
  - » Acquire user's proxy credentials
  - » Replica Selection: Consult replica catalog for available data, select replica "closest to the desired output location"
  - » Request Planner:
    - – If data available: plan necessary data movement
    - – Else: Construct a plan to produce data not available, including execution location selection. Select input data location ("close to compute resources"), schedule data movements etc…
    - – Specify plan in DAGMan format (a Condor-G specification format)
  - » Request Executor: submit DAGMan specified plan to Condor-G
  - » Return requested data to the user specified location in Frame format
  - » Provide a graphical view of the data by using the XSIL frame viewer.

iVDGL

- iVDGL will provide resources to deploy, support (in a limited fashion) the first 2 LIGO Tier 2 centers:
  - » UWM
    - – extension of existing MRI-funded hardware - provides out-year hardware renewal
  - » PSU
    - – greenfield Tier 2 center to be implemented by end of CY2002
  - » Limited FTE support to operate centers
    - – Postdocs, students
    - – Matching university funds from PSU will provide limited IT support

iVDGL Trans-oceanic testbed

- LIGO and Virgo have agreed to implementation of a data exchange protocol based on grid technology
  - » Exchange limited environmental channels to explore geophysical tele-correlations in anticipation of future network analysis using Virgo, LIGO as an array.
  - » Current prototype system developed by LIGO postdoc, CACR scientist, and Virgo collaborators
- Plan is to work with Virgo to migrate to grid toolkit to provide more robust, automated data exchanges around the clock
  - » Fits into the US-EU grid collaboration strategy

ITR 2003
Proposal to NSF for iVDGL Operations

- ITR 2003 announcement of opportunity expected from NSF this summer
- LSC Computing Committee organizing a collaboration-wide proposal to request funding to operate LSC Tier 2 centers for LIGO Science Run(s)
  - » *ITR2000: GriPhyN ->C/S + Applications R&D, prototyping*
  - » *ITR2001: iVDGL-> Center buildup (2 for LSC), port, install GriPhyN deliverables to Tier 2 centers*
  - » ITR2003: request manpower to operate centers ***to do the science***
    - – Scientists, systems adminstration (~ 10 FTE across 2 LSC sites, Lab. sites)
    - – Help desk, 7x24 operations support

LIGO

Data & Computing
- Personnel -

Data & Computing Personnel

				MIT				LHO			
	Classification	FTE		Classificati	FTE			Classificati	FTE		Classificati	FTE
Lazzarini	Sci/Mgr	1	Katsavoun	Faculty	-	Mendell		Sci	1	Yakushin	Sci	1
Blackburn	Sci/TskLdr]	1	Bayer	SysAmdin	0.5					Roddy	SysAmdin	0.5
Anderson	Sci/TskLdr	0.9										
Shawhan	Sci	1										
Charlton	Sci/Postdoc	1										
Wen	Sci/Postdoc	0.5 (+ 0.5LISA)										
Creighton	Sci/Postdoc	0.5 (+ 0.5LISA)										
Sylvestre	Sci/Postdoc	0.5 (+ 0.5LISA)										
Pan	GRStudent	1 (Prince)										
Hua	GRStudent	1 (Prince)										
Maros	SWEng	1										
Ehrens	SWEng/Contract	1										
Barnes	SWEng/Contract	1										
Lei	SWEng/Contract	1										
Salzman	SWEng/Contract	1										
McWhorter	SWEng/Contract	1										
Wilson	SysAdmin/Conti	1										
Kozak	SysAdmin/Conti	1										
Yamamoto	Sci	1										
Bhawal	Sci	1										
Sears	SWEng	1										
Evans	SWEng	1										
Araya	SWEng/Contract	1										
Wallace	SysAdmin	1	Bayer	SysAmdin	0.5	Patton		SysAmdin	0.5	Roddy	SysAmdin	0.5
Bogue	SysAdmin/Conti	1										
Pedraza	SysAdmin/Conti	1										
Kondrashov	WebAdmin	0.8										

Gen

FINIS

Significant Performance Improvements to 0.3.0

- Implemented TCL Channel for data sockets communications.
  - » Corrected almost all FILO (first in, last out) staging of jobs
  - » Tripled average throughput rate of jobs in busy system
- Reduced overhead for MPI from over 35 seconds per job to under 5 seconds.
- Removed known thread safety bugs, increasing concurrency in dataConditionAPI.
- Fixed code in-lining and optimization issues to allow for fully optimized build and running of LDAS.
- Removed major memory leaks resulting in greater duty cycle for individual LDAS APIs.

LDAS computational resources planned to be available for on-line processing during S1

LHO

machine	services	hardware
Gateway	managerAPI/cmonAPI/WWW/NFS	E450 4x400MHz/4MB/4GB/560GB
Metaserver	metadataAPI/DB2	E450 4x400MHz/4MB/4GB/420GB
Dataserver	frameAPI/diskcacheAPI	V880 4x750MHz/8MB/8GB
	raw frames	8.5TB
	reduced frames	2.1TB
	data archive	30 slot/2xAIT-2 robot
Datacon	datacondAPI	Dell6400 4x700MHz/1MB/2GB
Beowulf	mpiAPI	Dell2400 2x933MHz/256kB/1GB
Node1-64	search DSO's	64ea. 1x2GHz/512kB/512MB

LLO

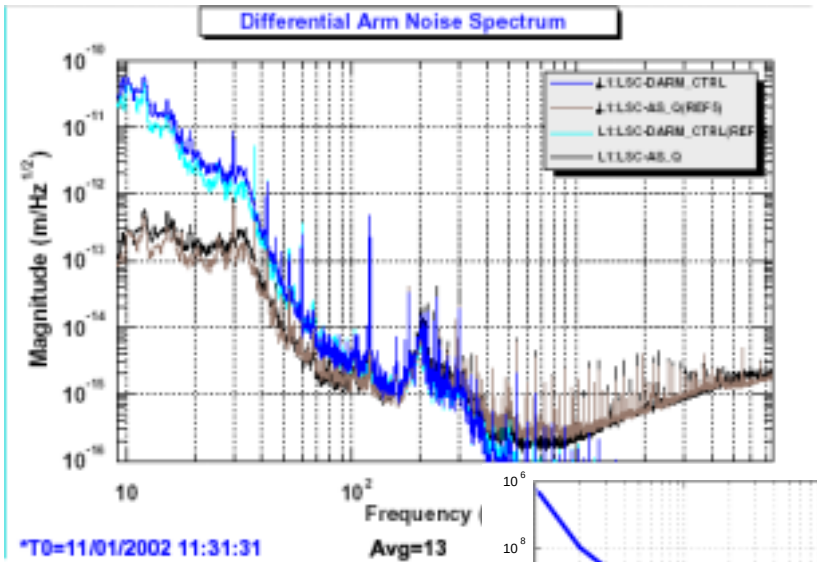
- Same except: (i) only 48 nodes; (ii) 0.5 the dataserver disk storage; (iii) metaserver has 560GB.

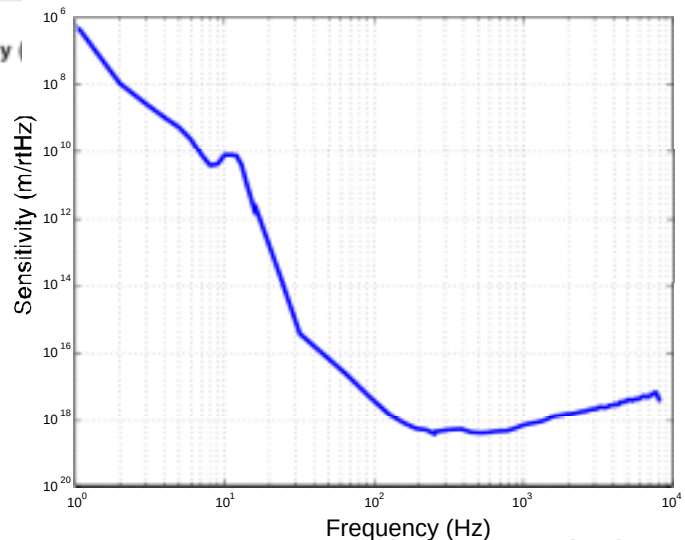
Networks

- All servers running Gigabit Ethernet
- All compute nodes running Fast Ethernet
- Dataserver and Gateway running 1Gbit/s Fibre Channel

Simulation of sensitivity curve

noise by realistic simulation





Simulation includes

- Locked interferometer
- Mechanics
- Sensor-actuator
- Servo electronics
- Signal extraction
- Simulated and measured noises
- …

Simulation of sensitivity curve

noise by realistic simulation